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ELECTRIC SEMICONDUCTOR COMPONENT

The present invention relates to an electric semiconductor component having a monocrystalline semiconductor substrate, an insulation layer arranged on the surface of the semiconductor substrate and penetrated by a contact hole in at least one location and a contact element which contacts the semiconductor substrate through the contact hole and is made of a material in which the semiconductor material of the substrate is soluble in an anisotropic dissolving process.

Such semiconductor components in which the semiconductor substrate is silicon and the material of the contact element is aluminum are widely used in general. One problem in establishing contact between aluminum and silicon in the area of the contact holes in such components is the solid-state reaction of aluminum with silicon taking place there. For a high conductivity of the contact between the two, it is necessary to remove the oxide film which is naturally always present between aluminum and silicon in the contact hole. This is accomplished by a temperature treatment in the range of 300°C to 500°C. At these temperatures, metallurgical reactions of aluminum with silicon occur due to the solid-state solubility of each substance in the other at locations where the oxide has been removed. The solubility of silicon in aluminum is in the order of a few percent (e.g., 0.48% at T = 450°C), depending on the temperature. The diffusion of silicon in polycrystalline aluminum is very high because of accelerated diffusion along grain boundaries. Therefore, in the course of the temperature treatment, not only is the direct contact hole area saturated with silicon but also the adjacent aluminum conductor regions become saturated with silicon. Depending on the temperature, a large quantity of silicon may be dissolved away from the surface of the semiconductor component and may migrate into the aluminum

contact structure. In a temperature treatment at 450°C for three minutes, for example, the diffusion length of the silicon atoms amounts to approx. 40 μm. The silicon atoms dissolved out of the crystal are replaced by aluminum atoms migrating out of the contact structure. They form "spikes" which are deposits of aluminum having a silicon content. The dimensions of these spikes become larger as the size of the contact hole becomes smaller and the volume of aluminum to be saturated in relation to it becomes larger. These spikes may greatly distort electric fields in the area of the contact hole or may lead to total failure of the component if they extend to a pn junction of the component.

To avoid this problem, it is known from D. H. Widmann, H. Mader, H. Friedrich, *Technologie hochintegrierter Schaltungen [Technology of Highly Integrated Circuits]*, Berlin, Springer 1996, for example, that silicon-doped aluminum may be used as the material for the contact structures of electronic components. The silicon concentration of the doped aluminum is greater than the solid-state solubility of silicon in aluminum, based on the highest process temperatures reached in the temperature treatment. This concentration may be approx. 1% silicon.

However, this method cannot be used for contacting in contact holes on high-resistance n-type silicon (donor concentration less than 10^{20} cm^{-3}). Epitaxial silicon deposits are formed in the contact hole area on cooling. These silicon deposits are doped with aluminum and therefore are p-conducting. Because of the formation of the pn junction, they have a negative effect on the contact resistance with increasing degrees of coverage in the contact hole. Therefore, aluminum without added silicon as the metallic coating is used for contacting high-resistance n-type silicon. To produce a conductive junction in the contact hole, the occurrence of spikes must be accepted.

Advantages of the Invention

The present invention is based on the surprising finding that the formation of spikes in a contact hole of a semiconductor component may be limited to a great extent by skillful design of the edges of the contact hole. It is not necessary to add additional structures, foreign substances, etc.

There are various design possibilities for the edges, which are referred to here as diffusion stop structures. Curved segments are the first possibility of this type. For example, a contact hole may be circular as a whole, or it may be composed of overlapping intersecting circles. The effect of the circular segment is based on the fact that it is composed of a plurality of linear segments, each having different directional indices, based on crystalline size dimensions, and that the dissolving process progresses differently along the individual linear segments until reaching the respective areas in the crystalline interior which present the greatest resistance to the dissolving process. The smaller the radius of such a circle, the shorter the corresponding linear segments and also the smaller the spikes which may emanate from a single linear segment.

A similar effect is achieved when the conventional straight bordering lines of a contact hole are replaced by microstructured sections. These microstructured sections may have a crenellated or sawtooth pattern, for example. Here again, the dissolving process proceeds regularly from a linear segment of the edge and progresses until reaching sparingly soluble crystal planes. Microstructuring achieves the result that the individual fronts where the dissolving process takes place are shortened in comparison with a rectilinear edge, and that accordingly only a smaller volume of the semiconductor material may be dissolved before reaching planes of the crystal that dissolve only slowly or not at all. It is true in general that the resulting spikes will be shorter as the microstructure becomes finer. A preferred edge length of the structure elements is 2 μm or less.

However, it is also possible to prevent or at least largely suppress the development of spikes on rectilinear edges of the contact holes. The anisotropy of the dissolving process implies that the semiconductor material has at least one class of crystal planes which are subject to little or no attack in the dissolving process. A class is understood to refer to a family of crystal planes whose Miller's indices arise from one another through permutation and/or sign reversal. All the planes of such a class are equivalent from a crystallographic standpoint. Rectilinear sections of the edges of a contact hole should preferably be arranged so that they intersect such crystal planes of the class running beneath the contact hole in the semiconductor substrate.

A contact hole may also be designed so that all its edges fulfill the above-mentioned requirement. Such a contact hole may be in the form of an equilateral triangle or overlapping, intersecting equilateral triangles.

The substrate of the semiconductor component is preferably a <111> silicon substrate, because the <111> plane of silicon is hardly subject to attack by dissolving in aluminum.

It is also possible to restrict the formation of spikes on such a substrate by the fact that the contact hole has edges which are rotated by ±15° toward the lines of intersection of the $<11\bar{1}>$ plane, the $<1\bar{1}1>$ plane or the $<\bar{1}11>$ plane with the surface.

Other features and advantages of the present invention are derived from the following description of exemplary embodiments with reference to the figures.

Figures

Figure 1 shows in a cross section a conventional semiconductor component to illustrate the problem of spike formation;

Figure 2 shows a surface of a semiconductor substrate having spikes formed at the edge of two contact holes;

Figure 3 shows a semiconductor surface having a contact hole according to the present invention in a top view and in a sectional view;

Figure 4 shows a variant of the contact hole from Figure 3;

Figure 5 shows a semiconductor surface having two circular holes according to the present invention;

Figure 6 shows a variant of the contact holes from Figure 5;

Figure 7 shows a semiconductor surface having two contact holes having microstructured edges according to the present invention;

Figure 8 shows two microstructured edges of a contact hole after a temperature treatment; and

Figure 9 shows a semiconductor surface having edges protected from the formation of spikes due to its orientation relative to planes that are sparingly soluble.

Description of the Exemplary Embodiments

To illustrate this problem, Figure 1 shows a section through an electronic component having a high-resistance semiconductor substrate 1 and two doped regions 2, 3 formed in it, which are to be separated from one another with a high resistance. An insulation layer 6 which is applied to the surface of the substrate has two contact windows 7 through which doped

regions 2, 3 are each connected to a contact element 4, 5 made of aluminum of the contact structure. There should not be a conducting connection between contact elements 4, 5. However, during a temperature treatment, which is necessary to produce a satisfactory electric contact between the doped regions and the contact elements, aluminum diffuses out of contact elements 4, 5 and into semiconductor substrate 1. Since the surface of semiconductor substrate 1 has a <111> orientation, the aluminum is not able to penetrate far into the depth of the substrate and therefore has spread out in parallel to the surface even more, and spikes 8, 9 have been formed starting from the various contact holes, establishing a conducting junction between regions 2, 3. Therefore, this component is not usable.

Figure 2 shows an enlarged detail of a surface of a silicon <111> wafer 20 having two contact holes 21, 22. This does not show the insulation layer at the surface of the wafer, only the edges of contact holes 21, 22 formed therein. A directional diagram inserted here shows the projections of the <11$\bar{1}$>, <1$\bar{1}$1> and <$\bar{1}$11> directions onto the plane of the figure. The edges of contact holes 21, 22 which are horizontal in the figure are parallel to a <110>-oriented flat of wafer 20. The vertical edges of contact holes 21, 22 at the left of the figure show almost no spikes, and the original silicon crystal shown with hatching extends directly to these edges. At all the other edges, spikes 23 extend far above the original edges of the contact holes to the substrate surface. The reason for this is the orientation of the edges relative to the crystal planes belonging to the same class as the surface. The vertical edges thus run parallel to the lines of intersection of a crystal face of this class which shall be arbitrarily designated as the <-111> plane here. This plane intersects left vertical edges 24, 25 of the two contact holes in an orientation such that it extends beneath the contact holes within the substrate. When in a tempering treatment an interface between silicon and aluminum propagates slowly

perpendicular to the <111> surface of the other substrate into the depth of the substrate, a <-111>-oriented interface develops immediately at edges 24, 25 and may also propagate only slowly into the interior of the substrate. However, <100> interfaces, which present only a low resistance to the dissolving process, are formed at right vertical edges 26, 27, so that spikes 23 are able to propagate there, as well as at the horizontal edges.

Figure 3 shows a contact hole of a semiconductor component according to a first embodiment of the present invention, Figure 3a shows the contact hole in a top view, and Figure 3b shows it in a section along the dash-dot line b-b from Figure 3a. The semiconductor substrate is a silicon substrate having a <111> surface. Contact hole 30 develops in the form of an equilateral triangle in an insulation layer 6 on the surface of substrate 1. As shown by the directional diagram, all three sides run parallel to the lines of intersection of the surface with crystal planes of the <111> class. The crystal planes run through semiconductor substrate 1 beneath the contact hole, as illustrated in Figure 3b on the basis of the example of the <$\bar{1}$11> plane. Region 3b in Figure 3b shows a zone in which the silicon of semiconductor substrate 1 has penetrated into substrate 1 due to a tempering treatment of a contact (not shown in this figure) made of aluminum attached in contact hole 30. All the interfaces between zone 31 and substrate 1 are class <111> crystal planes. The lateral propagation of zone 31 over the edges of contact hole 30 is correspondingly small. This propagation is indicated by dotted triangle 32 in Figure 3a.

It is not crucial for the present invention that contact hole 30 is an exact triangle with acute corners. The corners may also be truncated or rounded, and in this case interfaces between zone 31 containing aluminum and silicon substrate 1 which do not belong to class <111> might first be formed on them, unlike the ideal case of a triangle having acute

corners, but the final shape that could be achieved by the zone containing aluminum in such a case would also correspond to that of triangle 32.

Rectangular contact holes having unequal edge lengths are often desired for contacting semiconductor substrates. Figure 4 shows on the basis of a top view of a silicon <111> substrate having the same orientation as in Figure 3, how such a rectangular contact hole indicated by line 40 may be approximated by a plurality of overlapping mutually intersecting equilateral triangles. This yields an elongated contact hole 41 whose edges form a sawtooth pattern in some areas and in this way fulfill the requirement at all points that they should intersect crystal planes of class <111> running beneath the contact hole in the interior of the substrate.

Figure 5 shows a top view of a circular contact hole 50 on a silicon <111> surface which has exactly the same orientation as in Figures. 3 and 4. The edge of the contact hole has three regions 51 which at least approximately fulfill the same condition with regard to their orientation as the edges of the contact holes from Figures. 3 and 4. Accordingly, practically no spikes develop in these regions. In edge areas 52 in between, there are a great many spikes 53, but all of them have only a slight lateral extent. The reason for this is that the circular shape of contact hole 50, based on the size dimension of the crystal lattice, may be regarded as a result of many individual linear segments having different orientations and therefore resisting the dissolving attack of aluminum to different extents, and there is a plurality of lattice sites, e.g., at steps or corners of the interface between the silicon crystal and aluminum, which may function as a seed for the formation of spikes because of their emphasized coordination, or may prevent the propagation of spikes. Therefore, the process of dissolving silicon in aluminum proceeds from a plurality of points in close

proximity to one another along the edge and progresses radially outward from there, and the crystal faces of the <111> class, which are not as susceptible to attack, remain. As soon as two spikes have become so deep that their bordering faces are in contact, the dissolving process essentially comes to a standstill.

It is important here that the circular shape of contact hole 50 should be as accurate as possible. For comparison purposes, a second smaller contact hole 54 which is only approximately circular is also shown, its edge being made up of a small number of linear segments. Each linear segment here forms the starting point for a spike 53, and since the linear segments are relatively long in comparison with contact hole 50, relatively larger spikes are also formed here.

As shown by Figure 6 in a diagram similar to that in Figure 5, a rectangular contact hole may also be approximated by overlapping, intersecting circular contact holes, each having identical diameters r and spacings a_i.

Figure 7 shows other variants of contact holes which are also based on the finding that it is appropriate to avoid long, straight edge sections in order to limit propagation of the spikes. Therefore, in the case of contact hole 70, all the edges are crenellated, with small rectangular projections 71 of insulation layer 6 meshing into the interior of the contact hole. Projections 71 have a dimension a parallel to the edge and a dimension b perpendicular to that in the order of 2 μm or less each. The period of the crenelation may be 4 μm, for example.

As shown on the example of contact hole 72, these projections 71 may be omitted on an edge 73 whose orientation meets the condition defined for the edges of the triangle from Figure 3.

The effect of projections 71 is illustrated on the basis of Figure 8. The orientation of the semiconductor substrate, more specifically, that of its planes of class <111>, is the same in this figure as in Figures. 2 through 7. Figure 8 shows the pattern of an edge 80 of a contact element as a solid line. The edge is richly structured in a plurality of sections, intersecting one another at right angles. During tempering of the component, spikes 81 form along edge 80 and extend beneath the insulation layer until they are only surrounded by interfaces of class <111> which are difficult to attack. As shown by the comparison of the two edge patterns in Figure 8, these spikes are more numerous and smaller, the finer the structure of the edge.

Figure 9 shows a top view of a semiconductor substrate having a plurality of rectangular contact holes 90. The orientation of the semiconductor substrate is the same as that in the preceding figures. The edges of the contact holes here are rotated by ±15° in one of these three directions. This is the greatest angular deviation from one of the three directions that is possible at all on a surface having trigonal symmetry like the <111> surface of silicon. This orientation guarantees a plurality of exposed points along each edge from which spikes may form or which prevent the propagation of spikes. Therefore, in tempering the substrate, a large number and density of spikes are formed with aluminum contact elements attached in contact holes 90, but the growth of these spikes comes to a standstill in the course of the tempering process as soon as the sparingly soluble interfaces of the spikes begin to come in contact with one another.

The main points of the present invention have been described above from the standpoint of a silicon <111> surface and aluminum as the material at the contact elements. It would be readily conceivable to apply the present invention to other surfaces, in which case the spikes might then possibly extend into the depth of a substrate rather than parallel to the

surface, as well as other combinations of semiconductor material and metal. The only important thing is that the semiconductor material must have an anisotropic solubility characteristic with respect to the metal.